Using the Multirhodotron as an Advanced Rhodotron®

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Abstract

This article assesses the use of the new type of electron accelerator - Multirhodotron to energize FEL at the megawatt level of power in the continuous wave (CW) mode and for “electron cooling” in proton accelerators and colliders.

Introduction

More than 30 years ago, Dr. Pottier and Dr. Nguyen suggested a new idea regarding the acceleration of an electron beam in the radial electrical field of the coaxial resonant cavity energized by the TEM1 mode [1]. Accelerators of this type were trademarked as Rhodotron. For 30 years, the Belgian company IBA manufactured the entire line of these accelerators (TT 50-TT 1000) with power from 50 to 1000 kW for electron energy at an output of up to 10 MeV [2]. These 100-200 MHz accelerators have excessively large cavity dimensions. Their radiuses and weights are up to 1-1.3 meters and 8-10 tons, respectively. Such accelerators allow only 7-10 passes of an electron beam through the cavity because all of the trajectories of an electron beam lay in the single middle plane of the cavity.

The length of coaxial cavity of Rhodotron - λ/2
The number of planes for acceleration - 1

The length of coaxial cavity of Multirhodotron - (1-2)λ
The number of planes for acceleration - (2-4)

Results of simulations dynamics of electrons in Multirhodotron

- *large electrical gap where all of the electrons of the beam obtain the first acceleration after injection from a non-relativistic injector (80-100 kV) provides good capture of the electrons into the acceleration region. Simulations of electron dynamics in this gap have shown that all of the electrons that are in an interval with a length of π/2 are grouping in the interval which will be in four times smaller, with a length of approximately ~π/8, providing a 25% capture rate. This is shown in FIG. 1.*

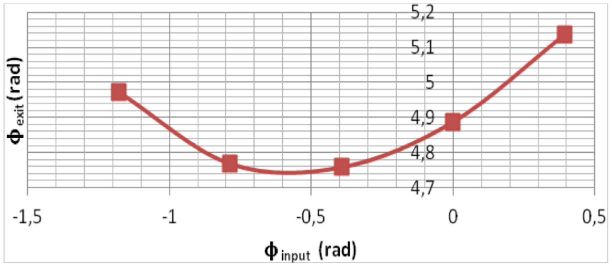

Fig.1

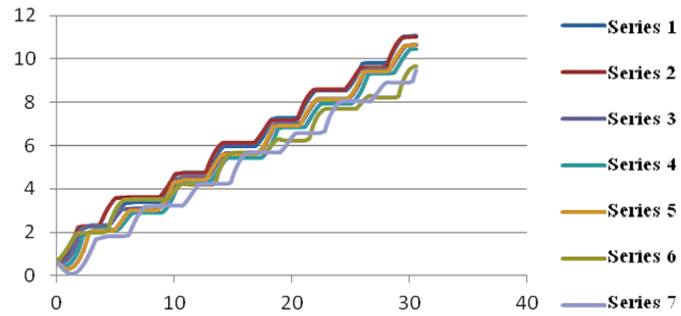

Fig.2

- *The simulation of the initial stage of acceleration for four passages through the cavity is illustrated in FIG. 2. The trajectories of the electrons with ϕ = -1.5708 (Series 6) and ϕ = 0.7854 (Series 7) are also shown. These trajectories (Series 6, 7) further leave the acceleration region.*

- *The designing of accelerator, based at the coaxial cavities, with the use of TEM modes of higher order radically changes the situation. They have two or more planes where the radial electrical field in the cavity has maximums [4] and all of the electron beam passages can be placed in these planes. This accelerator is called Multirhodotron*
- *The trajectories of the electron beam in Multirhodotron can be designed accordingly using variants (a, b) in FIG. 3 and they will be allocated in the first and second planes, where the electric field has maximum amplitude.*

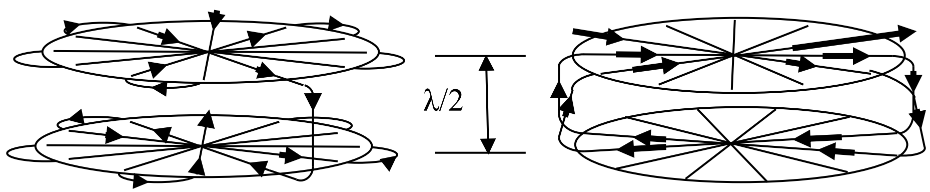

Fig.3

- *The simulation (Fig.4) shows that there is a zone of longitudinal phase stability that is equal to π/8 or slightly more for the sixteen passages through the cavity placed in two planes of the variant (b).*
- *The simulation of other event shows that the initial area of longitudinal phase stability also exists in the region of deceleration (FIG. 5). Reducing the electrons' energy in this beam can continue almost to zero.*

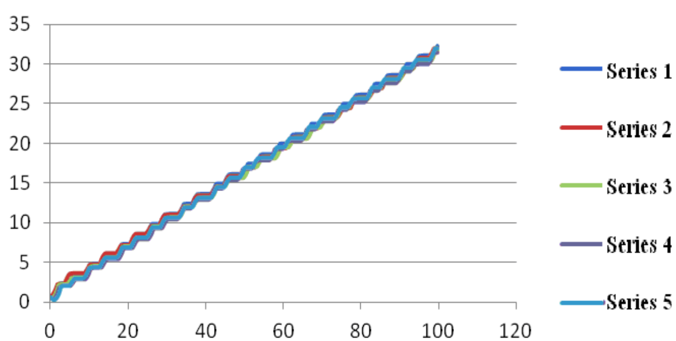

Fig.4

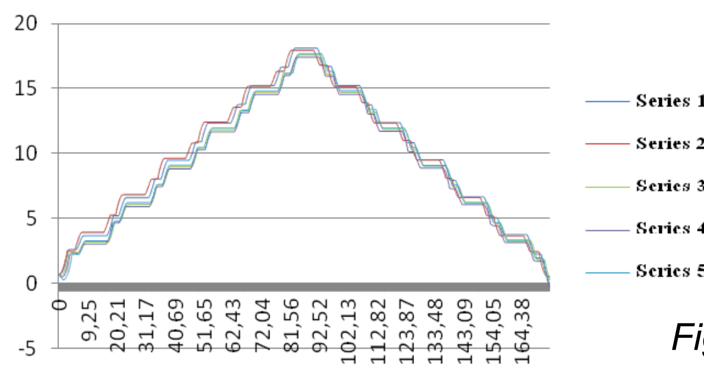

Fig.5

Discussion of the possible Multirhodotron's application

The trend behind the increase of electron's energy at the exit of the accelerator and the minimizing of the accelerator's footprint that was declared in the Second generation Rhodotron [3] apparently has been dictated by the necessities of the new types of the application of this accelerator.

These possible applications FOR ELECTRON ACCELERATOR MULTIRHODOTRON might be:
- *The manufacture of many types of radioactive isotopes for the medicine and other industries (instead of the use of nuclear reactors) [3]*
- *The miniaturization of the accelerator for the low-power applications [3]*

(to abovementioned might be added)
- *The energizing of the powerful FEL [7, 8]*
- *The "electron cooling" for proton accelerators and colliders [11].*

The MULTIRHODOTRON keeps all advantages of the focusing of electrons as in the beam being accelerated in the RHODOTRON but in addition to this fact the MULTIRHODOTRON can also keep or maybe increase the number of passages through the coaxial cavity even under the decreasing of all dimensions of acceleration cavity in accordance with the increase of the resonant frequency.

Possible variants of overall dimensions for MULTIRHODOTRON's cavity:

200 MHz (λ = 1.5 M)	*R = 50 sm*	*H = 300 sm*	*N = 4 x (9-11) passes*
300 MHz (λ = 1 M)	*R = 35 sm*	*H = 200 sm*	*N = 4 x (7-8) passes.*

These variants allow reaching about 50 MeV in electrons' energy at the output of accelerator without of the significant increase of the electromagnetic field in the cavity in comparison with the RHODOTRON of the first generation.

The probability of the energizing of the BBU instability (Beam Break Up) is increasing due to the large number of passes of the electron beam through the cavity like in the usual linac. This effect limits the maximum electron current of the accelerating beam as in the linac so in RHODOTRON (100mA for TT-1000) and MULTIRHODOTRON too. In accordance with our assuming the most likely reason for this instability is the following dependency.

The all even harmonics of TEM (TEM_{2n}, n = 2, 4…) in the middle plane of the Rhodotron's cavity have maximum magnetic fields and electric fields equal to zero. If during one passage the magnetic fields of these modes deflect all electrons of bunches from the middle plane into the area near the middle plane where the electric fields of these oscillations are already not equal to zero, then the electron bunches will be decelerated in the next passage by these electric fields in this area and thus the amplitudes of these modes will increase in the cavity. This dependency can be simply confirmed analytically. This can be also established using experimental measures registering the HOMs oscillations in the cavity by a spectrometer, under simultaneously increasing the accelerator's current.

This defect can be easily removed by means of small changes in the cavity that increase the attenuation of HOMs TEM2n, n = 2, 4… . This result can be obtained if two slits are made in the inner and external cylinders of the resonant coaxial cavity in the middle plane and perpendicularly to the cavity axis. The length of the initial whole cavity is equal to λ/2, but with these slits the whole cavity will consist of two insulated halves of the coaxial cylinders and the length of each of half will be equal to λ/4. In this case, all modes of TEM (2n+1), n = 1, 3… that have not currents through the cavity slits, will not be attenuated. However, for all currents for the modes TEM2n, n = 2, 4... in the cavity walls that cross these slits the energizing conditions of these oscillations will not be met.

The analogical method can also be used for the Multirhodotron to provide a larger number of passages of electron beam through the cavity, especially if there are two, three, or four planes for the electron beam under the moving through the cavity.

The aforementioned method can also enable an increase of the current of electron beam under acceleration in the Rhodotron or Multirhodotron, because the limitation of the current of the electron beam in an accelerator like Rhodotron (with the coaxial cavity), countable through the rigidity of the focusing forces, significantly exceeds the current's limit of BBU instability.

In accordance with the estimation of this limit in his dissertation [8] Dr. Bassaler operates with the currents of the electron beam about (3-10) of amperes in the different applications, exceeding the BBU current's limit more than in ten times. The validity of this estimation can be simply confirmed analytically therefore the increase of number passages of the electron beam through the cavity will not lead to the diminution of the current's limit for the accelerator, if the all standards of the struggle with BBU instability have been met. But in these cases more powerful generators will be necessary for the supplying of HF power to the accelerators' cavities [9, 10].

The separate interest is that the application of the Multirhodotron, as the source for the energizing the FEL's wiggler, for one side gives the possibility to come back the all accumulated energy of the electron beam after the crossing the wiggler into the energy of the electromagnetic field in the accelerating cavity [6, 7]. But for other side the large number of the passes through the cavity gives the possibility to use 3-5 wigglers, alternating their with the additional accelerating passages like is shown in Fig. 6.

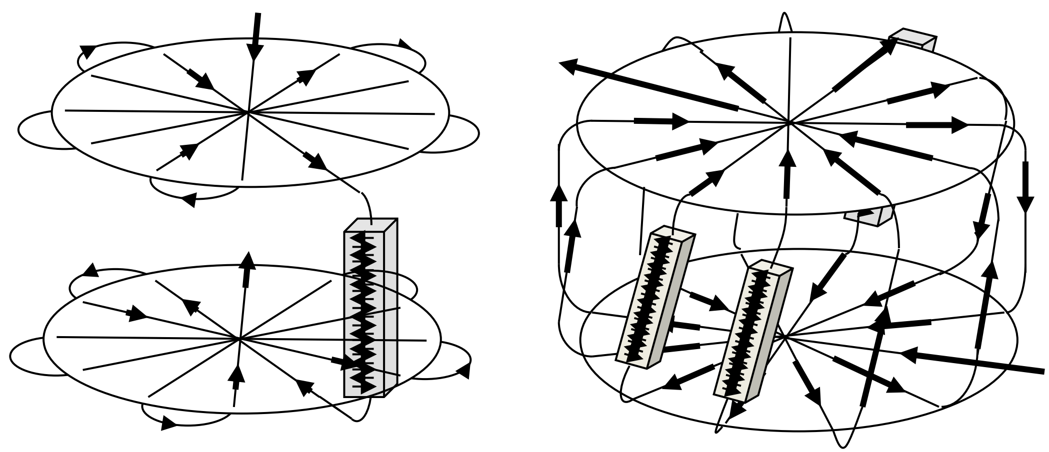

FIG. 6

In this case the all wigglers of the FEL may be connected in series or in parallel lengthways of the same flow of light by means of several lenses and mirrors. But at the same time the different periods and meanings of magnetic fields have to be used in accordance to the energy of the electron beam in each wiggler for the generating of the light of the same wave-length accordingly with the formula $\lambda = (1 + \alpha^2 w/^2)\ \lambda_0/2\gamma^2$.

The efficiency of each wiggler is about 1% from the energy of the electron beam therefore if the energy is equal to 20 MeV and the current of the beam is equal to 1 A and are used 5 wigglers in series, the total power of the FEL will be about one megawatt at the exit.

Also not large losses of the electrons' energy are present in the beams accelerated by means of linac that are suggested to use in the technologies of "electron cooling" [11]. The level of energy and the current of the electron beam lay in the area where the Multirhodotron might be used and the use of the method of the recuperating of the remaining energy of the beam will give possibility to exploit these devices with high efficiency.

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